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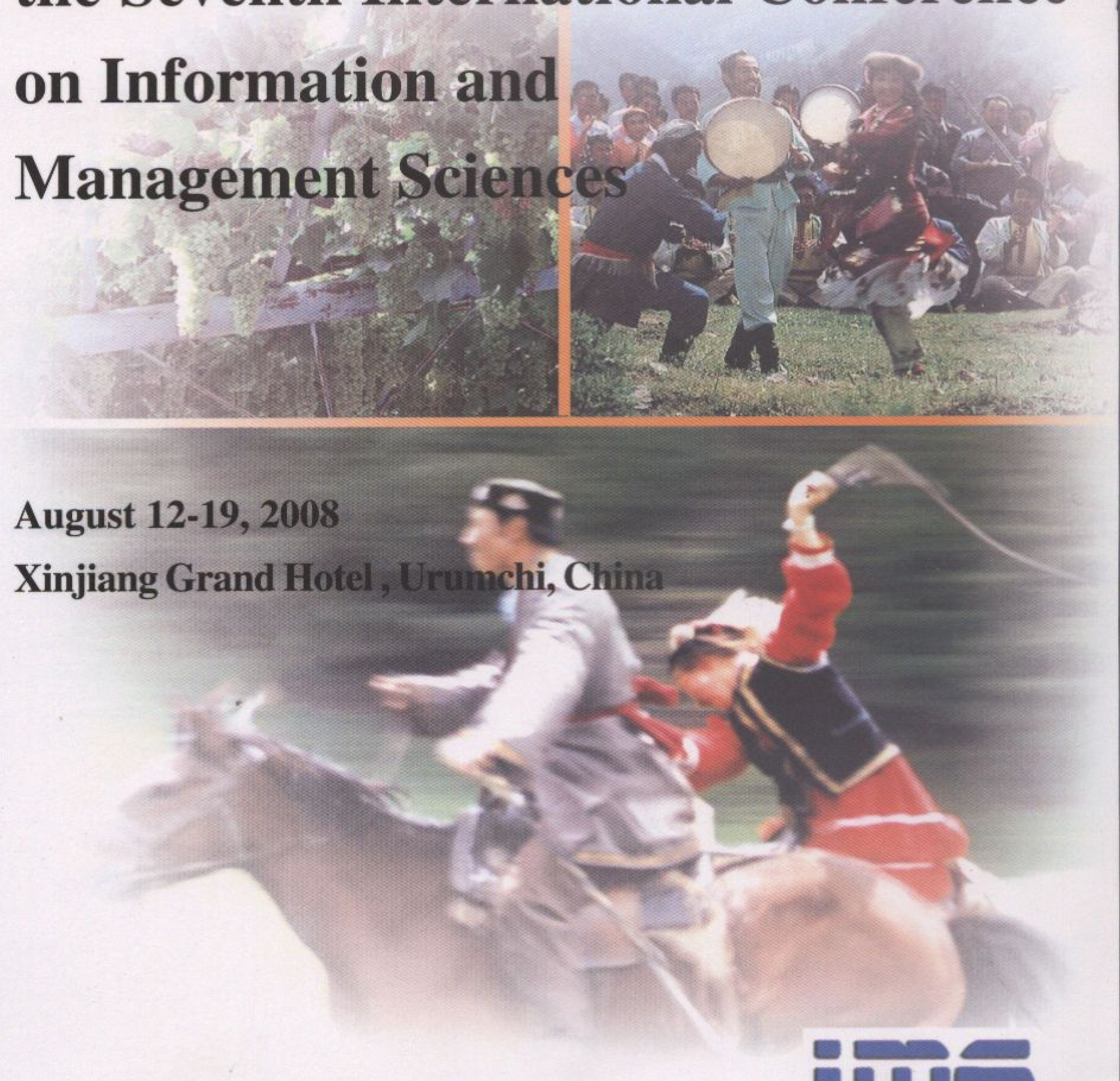

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Application of Fuzzy Analysis in Comprehensive Evaluation in SP Flooding Test of Daqing Oilfield

Yanqiu Gong[1], Hao Yuan[2], Yuliang Feng[3], Wenyu Liu[4], Bing Huang[4]
1 Daqing Petroleum Institute, Daqing, Heilongjiang 163318
2 Department of Chemical Engineering, Technical University of Denmark, Copenhagen, DK-2800
3 College of Automation; Nanjing University of Science and Technology, Nanjing; Jiangsu 210094
4 Dagang Oil Field Company, Tianjin, 300280

Abstract: There are several economic indexes must be taken into account besides many technical indexes during the decision and optimization in oilfield. These technical and economic indexes must be considered together at the same time, and they can be combined reasonably by fuzzy analysis method. The results can provide direct and quick assessment data for the operator. It's simple, more integrated, more scientific and more comprehensive results can be gained. SP flooding in No.2 oil production plant was discussed in this paper, the fuzzy analysis data indicated a good results.

Keywords: fuzzy analysis, SP flooding, comprehensive evaluation

1 Introduction

Since 1993, the application of ASP flooding has been enhanced in Daqing oilfield, 5 pilot sites were carried out and the results indicate an increased recovery of OOIP by more than 20% after water flooding. With the development of surfactant agent produced in Daqing and its successful application in Daqing oilfield, the number of ASP flooding pilot sites increases to 14 now. But with the benefit of its ability to increase the recovery, some other things become obvious, such as crustation, stuck pump, and so on. These problems has become the bottle neck of the application of ASP flooding. So, to avoid these problems during ASP flooding, and to achieve a better oil recovery, without the alkali, study on SP flooding certainly begins.

Of course, the recovery of SP flooding is lower than that of ASP flooding, but SP flooding will never eat the injection and production pipes, so we can cut some injection equipment, and the pump inspection period is shorten, the economic effect is better than that of ASP flooding. But some people will only focus on the final recovery, the economic effect will always be the second in their mind. Actually, we can't make the decision only by technical specification, or the economic effect, these two must be considered at the same time. The technical and economic effects must be combined reasonably, and only by this way, the comprehensive evaluation can be scientific and effective.

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Technical and economic indexes were taken into account at the same time by the use of fuzzy analysis method in Daqing SP flooding, and the result was given to guide the application in oilfield.

There are five steps to make the decision:

1. Technical and economic indexes calculation;
2. Normalization of indexes;
3. Indexes evaluation matrix calculation;
4. The weights of all the technical and economic indexes;
5. Comprehensive evaluation result, to make the decision.

2 Calculation of Technical and Economic Indexes of the Project

Although the lab experiment can guide the field in some way, but there is somewhat difference between lab experiment and field effect. So, for the technical indexes of pilot tests in oilfield, the main methods to predict are comprehensive analysis by dynamic data and reservoir simulation. The main indexes include periodic oil recovery, water cut falloff and low water cut period. For economic indexes, IRR(Internal Rate of Return) and payback period are the two main aspects.

3 Technical and Economic Indexes Processing

First, the intervals of all the technical and economic indexes should be defined according to the industry standard and their ranges (**Tab.1**), and then according to **EQ.1** and **EQ.2**, all these indexes should be processed.

For index $X_i \in [X_{\min}, X_{\max}]$, which belongs to the type of the bigger the better, so we have[1]:

$$x_i = \left| \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \right| \tag{1}$$

For the type of the smaller the better,

$$x_i = 1 - \left| \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \right| \tag{2}$$

Where i is the number of indexes, $i = 1,2,\cdots n$, in this paper $n = 5$.

Table 1 Range of all the indexes in SP pilot test in No.2 oil production plant in Daqing oilfield

No.	symbol	index	unit	range
1	X_1	Periodic oil recovery	%	[5,20]
2	X_2	Water cut falloff	%	[0,25]
3	X_3	Low water cut period	month	[0,18]
4	X_4	IRR	%	[0,50]
5	X_5	Payback period	year	[1,5]

4 Indexes Evaluation Matrix Calculation

According to the need of final comprehensive evaluation, we divide the range [0,1] into four levels, the details are as followings in **Tab.2**:

Table 2 Divided levels of the comprehensive evaluation

levels	bad	ordinary	good	better
range[Y,Z]	[0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]

Evaluation level vector V is calculated as:

$$V = [v_1, v_2, \cdots, v_m]^T \tag{3}$$

$$v_j = y_j + \frac{z_i - y_j}{2} \tag{4}$$

Where j is the number of levels, $j = 1,2,\cdots m$, in this paper there are four levels, so $m = 4$. Fuzzy matrix is:

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \cdot & \vdots \\ r_{n1} & & r_{nm} \end{bmatrix} \tag{5}$$

Where r_{ij} is the probability of index i belongs to level j, $r_{ij} = 1 - |x_i - v_j|$

5 Weights of All the Technical and Economic Indexes

There are many ways to calculate the weight, the usual way is improved analytical hierarchy process, expert scoring method, or principal components analysis.

5.1 Expert scoring method[2]

Expert scoring method is to give the weight coefficient by people's experience. In order to avoid some person's hobby of particular indexes, experts are needed as many as possible in theory, and the average of all the weight coefficients will be available. But in practice, this result is easily influenced by people's knowledge and hobby, if there are not enough experts, or some experts only focus on technical indexes or economic indexes, the results will be greatly different. This method is simple, no complex calculation, if all the experts have a good understanding of the problem, the result can represent main contradictory, and it's suitable for practical work anyway.

5.2 Improved analytical hierarchy process[3]

Another name of this method is "three standard degree method", its important character is: comparing the two indexes x and y, if x is more important than y, we have $C_{xy} = 2$; if x is as important as y, we have $C_{xy} = 1$; and if x is less important than y, we finally have $C_{xy}^* = 0$. Details of comparison can accord to market needs or the importance difference between the indexes, repeated calculation should be done to check the results. All the comparison results between two indexes can form the comparison matrix C:

$$C = \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1n} \\ C_{21} & C_{22} & \cdots & C_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ C_{n1} & C_{n2} & \cdots & C_{mn} \end{bmatrix} \tag{6}$$

where C_{ij} is the comparison result between two indexes.

$$C_{ij} = \begin{cases} 2 & \text{when index } i \text{ is more important than index } j \\ 1 & \text{when index } i \text{ is as important as index } j \\ 0 & \text{when index } i \text{ is less important than index } j \end{cases}$$

where n is the number of indexes. Obviously, $C_{ii} = 1$, we define the order of importance r_i:

$$r_i = \sum_{j=1}^{n} C_{ij} \tag{7}$$

Judgement matrix $B = [b_{ij}]$ is formed from matrix R:

$$b_{ij} = \begin{cases} \dfrac{(r_i - r_j)}{(r_{\max} - r_{\min})}(b_m - 1) + 1, & r_i > r_j \\ 1, & r_i = r_j \\ [\dfrac{(r_j - r_i)}{(r_{\max} - r_{\min})}(b_m - 1) + 1]^{-1}, & r_i < r_j \end{cases} \tag{8}$$

where $b_m = r_{\max} / r_{\min}$, $r_{\max} = \max r_i (1 \le i \le n)$, $r_{\min} = \min r_i (1 \le i \le n)$.

But there is one point we must pay attention to, the judgement matrix as above isn't in accordance with the consistency of humankind's thinking. For example, if index x is more important than index y, and index y is more important than index z, so we know that, index x is much more important than index z. But in fact, index x is as important as index z, this is caused by not in accordance with the consistency of humankind's thinking. So, we can improve matrix B by optimal transfer matrix, after this, the consistency will be automatically fulfilled, and the weight can be calculated directly. Now, we have,

$$a_{ij} = 1gb_{ij}$$

$$c_{ij} = \sum_{k=1}^{n} (a_{ik} - a_{jk}) / n \quad (9)$$

$$b_{ij}^{*} = 10^{c_{ij}}$$

So the matrix $B^{*} = (b_{ij}^{*})_{n\times n}$ has a good consistency. B^{*} is the judgement matrix, the eigenvector $W = [w_1, w_2, \cdots, w_n]^T$ can be calculated, and all the parameters of W is the weight of indexes. Eigenvector calculated by square root method is as followings,

$$\left.\begin{array}{l} u_i = \prod_{j=1}^{n} b_{ij}^{*} \\ \overline{w} = (u_i)^{\frac{1}{n}} \end{array}\right\} (i = 1, 2, \cdots, n) \quad (10)$$

Standardization of vector $\overline{w} = [\overline{w}_1, \overline{w}_2, \cdots, \overline{w}_n]^T$ is:

$$w_i = \frac{\overline{w}_i}{\sum_{j=1}^{n} \overline{w}_j} \quad (11)$$

So the vector $W = [w_1, w_2, \cdots, w_n]^T$ is the index's weight, and $\sum_{i=1}^{n} w_i = 1$

6 Comprehensive Evaluation Results Calculation

The evaluation result can be gained by multiply weight vector W with judgement matrix R:

$$B = W \cdot R = [b_1, b_2, \cdots b_m]^T \quad (12)$$

As we have the evaluation level vector $V = [v_1, v_2, \cdots, v_m]^T$ and evaluation result $B = [b_1, b_2, \cdots b_m]^T$, comprehensive result D is:

$$D = \frac{\sum_{i=1}^{m} b_i v_i}{\sum_{i=1}^{m} b_i} \quad (13)$$

The level that D is in is the comprehensive evaluation result of the whole project.

7 Application in Daqing Sp Flooding Area

After a lot of lab experiments, surfactant that is suitable for the underground water in Daqing oilfield was selected, and on the basis of different multisystems with various polymers, final injection project was worked out. But some people will doubt that whether SP flooding can gain a good oil recovery, or if it can gain a good oil recovery, can the project be economical? Which is better in whole comparing to ASP flooding, including technical and economic indexes?

Three technical indexes(periodic oil recovery, water cut falloff and low water cut period) and two economic indexes(internal rate of return and payback period) were calculated and chosen to evaluate the feasibility of SP flooding in NO.2 oil production plant in Daqing oilfield.

7.1 Technical and economic indexes normalization

According to **EQ.1** and **EQ.2**, the result is shown in **Tab.3**.

Table 3 technical and economic indexes normalization result of SP flooding project

No.	symbol	index	unit	range	result
1	X_1	Periodic oil recovery	%	[5,20]	0.867
2	X_2	Water cut falloff	%	[0,25]	0.8
3	X_3	Low water cut period	month	[0,18]	0.667
4	X_4	IRR	%	[0,50]	0.6
5	X_5	Payback period	year	[1,5]	0.722

So we have $X = [x_1, x_2, \cdots, x_n]^T$ =[0.867, 0.8, 0.667, 0.6, 0.722]^T

7.2 Evaluation matrix result

Evaluation level range division is shown in **Tab.4**, interval [0,1] is divided into four levels.

Table 4 evaluation levels

levels	bad	ordinary	good	better
range[Y,Z]	[0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]

Evaluation level vector can be calculated by **EQ.3**.

$V = [v_1, v_2, \cdots, v_m]^T$ =[0.125, 0.375, 0.625, 0.875]^T

So, the evaluation matrix R is

$$R = \begin{bmatrix} 0.258 & 0.508 & 0.758 & 0.992 \\ 0.325 & 0.575 & 0.825 & 0.925 \\ 0.458 & 0.708 & 0.958 & 0.792 \\ 0.525 & 0.775 & 0.975 & 0.725 \\ 0.403 & 0.653 & 0.903 & 0.847 \end{bmatrix}$$

7.3 Weights of all the indexes

For simplification, the weights of all the technical and economic indexes are given by expert scoring method:

So, we can get $W = [w_1, w_2, \cdots, w_n]^T$ =[0.3, 0.15, 0.15, 0.2, 0.2]^T。

7.4 Comprehensive evaluation result

According to **EQ.11**, evaluation result is as below:

$$B = [0.3804, 0.6305, 0.8704, 0.8696]^T$$

Table 5 weights of technical and economic indexes by expert scoring method

Indexes	Periodic oil recovery	Water cut falloff	Low water cut period	IRR	Payback period
Weight/%	30	15	15	20	20

Comprehensive evaluation result calculated by **EQ.12**, D=0.5776, it is in the level of good. So for this project, its technical and economic indexes were both good, and of course its good. Besides, for ASP flooding, the comprehensive evaluation result is only 0.4998, it is ordinary, so, according to our comprehensive evaluation result, SP flooding is better than ASP flooding in whole.

8 Conclusions

1 Technical and economic indexes are both considered in the evaluation process, and these two are combined reasonably by proper weights, the final comprehensive evaluation result can guide the operation work in oilfield;

2 This method is simple, scientific, reasonable, and the result can avoid the preference to some particular indexes;

3 During the comparison of many projects, this method can give the comprehensive evaluation results directly, it's simple and can save a lot of work.

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